

They think they can make fuel from horse manure. Now, I don't know if your car will be able to get 30 miles to the gallon, but it's sure gonna put a stop to siphoning.

Billie Holiday (1915–1959)

## FUELS

# Corn Ethanol Goal Revives Dead Zone Concerns

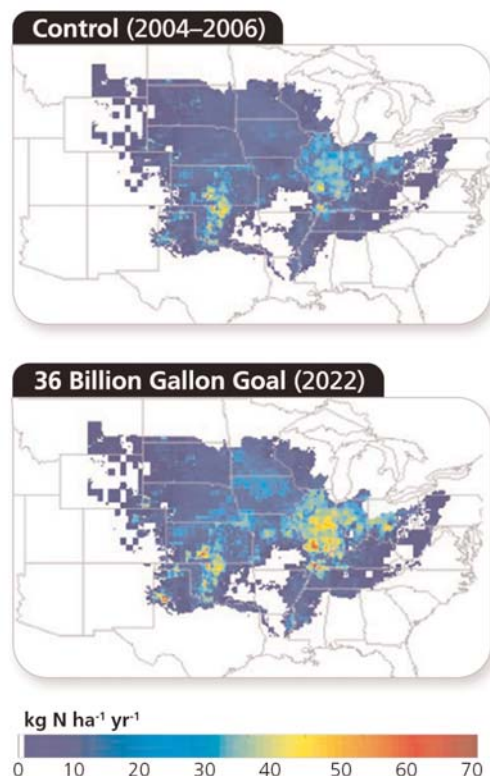
The Energy Independence and Security Act of 2007 calls for the production of 36 billion gallons of renewable fuels by 2022, including 15 billion gallons of corn-based ethanol, a tripling of current production that would require a similar increase in corn production. Yet scientists are coming to understand that biofuels, which originally sounded like a sensible response to the twin problems of climate change and dependence on foreign oil, create environmental problems of their own. One such problem is an increase in nitrogen runoff as farmers rush to plant more corn to meet growing demand for ethanol. According to the National Corn Growers Association,

rising corn prices prompted farmers to plant 92.9 million acres of the grain in 2007, a 19% increase over the prior year.

Fred Below, a professor of crop physiology at the University of Illinois at Urbana–Champaign, explains that corn requires more nitrogen fertilizer compared with other crops because of its higher production of grain per unit area than other crops. “Also,” he adds, “unlike crops like soybeans that form symbiotic relationships with soil bacteria to obtain a portion of their nitrogen from the atmosphere, corn is completely dependent on available nitrogen in soil.” Naturally occurring nitrogen usually

must be supplemented with fertilizer to meet corn's needs.

The nitrogen applied as fertilizer to corn does not stay in the Corn Belt. Instead, it travels via local streams and rivers to the Mississippi River and eventually enters the Gulf of Mexico. Once there, the excess nitrogen fuels explosive algal blooms. When the algae die, they are decomposed by bacteria that consume much of the oxygen in the water. The result is a so-called Dead Zone about the size of New Jersey that is so depleted of oxygen that fish, shellfish, and other aquatic life cannot survive there. The boom in biofuel production “is a disaster for the



Simulated nitrogen loading reflects corn production in 2004–2006 and in 2022 if the United States were to achieve the goal of producing 36 billion gallons of renewable fuels (including 15 billion gallons of corn ethanol) set forth in the Energy Independence and Security Act.

Source: Donner and Kucharik. *Proc Natl Acad Sci USA* 105:4513–4518 (2008).



Photo: Jack Webster

Gulf of Mexico,” says Simon Donner, an assistant geography professor at the University of British Columbia. “Nitrogen already is a big problem, and the new energy policy will make it worse.”

Donner and Chris Kucharik, an associate scientist at the University of Wisconsin–Madison, are the first to quantify how the corn ethanol boom may impact the Gulf. They used established models that combine agricultural land use with nitrogen cycling. The results, reported 18 March 2008 in *Proceedings of the National Academy of Sciences*, showed that scaling up corn production to meet the 15-billion-gallon goal would increase nitrogen loading in the Dead Zone by 10–18%. This would boost nitrogen levels to twice the level recommended by the Mississippi Basin/Gulf of Mexico Water Nutrient Task Force, a coalition of federal, state, and tribal agencies that has monitored the Dead Zone since 1997. The task force says a 30% reduction of nitrogen runoff is needed if the Dead Zone is to shrink.

Streams serve as natural filters to prevent nitrate pollution from reaching coastal waters. Bacteria in stream sediments remove nitrogen through denitrification, a process that converts nitrate to benign nitrogen gases that diffuse from the water into the air. However, increased levels of nitrogen runoff in local streams from urban and agriculture land use can overwhelm streams, which “become very inefficient and do not perform the ecological service we assume they do,” says Patrick Mulholland, an aquatic ecologist at Oak Ridge National Laboratory.

Mulholland coordinated a team of 31 ecologists who monitored 72 streams in 8 regions of the United States. The streams received runoff from agricultural lands, urban areas such as golf courses and housing subdivisions, or wild-growth vegetation. The team injected a small amount of  $^{15}\text{N}$ , a safe isotope of nitrogen, into waterways to track nitrogen movement and removal as small streams flowed into larger ones.

Although denitrification rates increased in tandem with rising nitrate concentrations, the process became very inefficient with a much smaller proportion of the nitrate removed from stream waters at higher nitrate concentrations. “Humans can easily overload stream and river networks, so a smaller proportion of the nitrate load is removed from the entire system,” says Mulholland. The team published these results in the 13 March 2008 issue of *Nature*.

Many scientists suggest converting cornfields to feedstocks that need little or no fertilization, such as switchgrass. No longer a dubious prospect, switchgrass proved its economic worth in the first large-scale field trial of the crop, published in the 15 January 2008 *Proceedings of the National Academy of*

*Sciences*. Ten farmers in Nebraska and the Dakotas grew 15- to 20-acre plots of switchgrass and recorded fuel, fertilizer, and herbicide inputs and grass production over a 5-year period. Plant geneticist Kenneth Vogel and colleagues at the U.S. Department of Agriculture (USDA) Agricultural Research Service at the University of Nebraska–Lincoln plugged these numbers into a biofuel analysis “meta-model” developed at the University of California, Berkeley, and described in the 27 January 2006 issue of *Science*. They calculated that the 3- to 5-foot-tall grass generated 540% more renewable energy than was needed to grow, harvest, and process it into ethanol. Moreover, switchgrass produced an average biomass equivalent of 320 gallons of ethanol per acre, similar to regional yields from corn. What’s more, they found that ethanol made from switchgrass emitted 94% less greenhouse gases compared with burning gasoline.

The baseline study “clearly demonstrates that switchgrass grown for biomass energy is very net energy positive, and its potential as a biomass energy crop on marginal cropland is promising,” Vogel says. Moreover, switchgrass residue remaining after ethanol processing could fuel biorefineries, whereas corn biorefineries burn natural gas or other fossil fuels. Vogel says USDA researchers are breeding new switchgrass cultivars specifically for bioenergy that grow to over 8 feet tall, yielding more biomass per acre.

The trick to advancing the use of alternative feedstocks such as switchgrass, corn stalks, and wood waste lies in finding enzymes to degrade the xylan, cellulose, and lignin in these cellulosic materials. Collectively known as lignocellulose, these three components make these plants strong and recalcitrant to known enzymatic methods of degradation.

Termites, however, rapidly digest wood. These insects have detailed mechanisms for converting lignocellulose into their own biofuel, says study coordinator Jared Leadbetter, an associate professor of environmental microbiology at the California Institute of Technology. A public–private team has now sequenced microorganisms that live in the hindgut of *Nasutitermes* termites to identify how the termites achieve this feat.

Two types of bacteria dominate the termite hindgut—treponomes, which ferment sugar, and fibrobacters, which specialize in breaking down lignocellulose. Several hundred genes related to enzymatic digestion of lignocellulose were identified. The team, which reported these results in the 22 November 2007 issue of *Nature*, is now growing the microbes in the laboratory in an attempt to better characterize the enzymes and pathways relevant for lignocellulose degradation.

**ehpnet** | by Erin E. Dooley

## NREL Biomass Research

<http://www.nrel.gov/biomass/>

The Department of Energy National Renewable Energy Laboratory (NREL) conducts numerous research, development, and demonstration projects in the field of biomass-based energy. Easy-to-understand, up-to-date information about these efforts is available in the “Biomass Research” section of the NREL website.

Under “Biomass Basics,” visitors find a glossary of biomass terms and a consumer guide, *Exploring Ways to Use Biomass Energy*. A short video featuring NREL scientists explains how cellulosic biomass such as corn waste and switchgrass is converted to liquid fuels as well as the environmental and economic benefits of these fuels. A FAQ section is organized into eight broad topics including biochemical conversion, biodiesel, ethanol, and feedstocks.

More technical materials are available in the “Energy Analysis & Tools” section, which includes three main focal points: technoeconomic analysis, life cycle assessments, and tools. Under “Publications,” visitors can access the Biomass Document Database, which archives public documents dating all the way back to 1980, or they may download project fact sheets, posters, and other publications.

Bacteria can generate another alternative fuel—hydrogen, a renewable, efficient, and clean energy source that powers fuel cells. *Escherichia coli*, better known for causing food poisoning, produces hydrogen when it feeds on glucose and formate, common ingredients in waste streams from sugar beet processing plants and breweries. In a bid to harness this potential fuel source, Thomas Wood, a chemical engineer at Texas A&M University, revved up hydrogen yields by inducing mutations in key metabolic pathways. A modified *E. coli* strain that feeds on glucose was shown to produce 5 times more hydrogen than the parent strain, and a formate-eating strain produced 141 times more hydrogen, as described in the January 2008 issue of *Microbial Biotechnology*.

Whereas ethanol production converts biomass into sugars, “we want to take that sugar and turn it into hydrogen,” says Wood. He envisions adding mixtures of microbes to waste streams that could devour different sugars and generate hydrogen. Ultimately, he says, homes may be outfitted with 250-gallon bioreactors (about the size of a home heating oil tank) to convert sugary wastes into hydrogen onsite to power appliances, lights, and computers. “It’s an exciting time to be involved in developing different fuel sources,” Wood says, “but we have to do it in a way that does not hurt the environment.” —Carol Potera



## CANCER

## UV Protection from Plants

Excessive exposure to the sun's ultraviolet (UV) rays can exact a heavy toll on skin health, resulting in an increased risk of skin cancers as well as other telltale signs of photoaging. In the United States alone, more than 1 million cases of skin cancer are diagnosed each year, accounting for almost 40% of all new cancer cases, according to the National Cancer Institute. Thus, the search continues for better ways to prevent the deleterious effects of too much sun. One approach, photochemoprotection, uses pharmacologically active plant-derived compounds, administered either orally or topically, to prevent carcinogenic sun damage.

A compelling feature of photochemoprotection is its focus on specific aspects of skin cancer biology. "Phytochemicals can be employed to intervene at the initiation, promotion, or progression stages of the multi-stage cancer process," says Farrukh Afaq, a dermatology researcher at the University of Wisconsin–Madison. "Since multiple pathways are involved in [the] photocarcinogenic response, a mixture of several phytochemicals working through different cell signaling pathways or other mechanisms could be an effective strategy."

A review by Afaq and colleagues in the March–April 2008 issue of *Photochemistry and Photobiology* summarizes the photochemoprotection strategies that show the most promise, among them green tea polyphenols (GTPs), grape seed proanthocyanidins (GSPs), resveratrol from grapes, silymarin from milk thistle, curcumin from turmeric, beta-carotene, and extracts of pomegranate fruit. Afaq notes that many of these compounds have been shown to target the NF- $\kappa$ B, AP-1, MAPK, and PI3K/AKT pathways, all of which are involved in photocarcinogenesis and the progression of skin cancers.

"Along with antioxidant, anti-inflammatory, and DNA repair effects, a number of these agents also have immune-modulating properties," says Santosh Katiyar, a dermatology professor at the University of Alabama at Birmingham who was not a part of the study. "This is important, since

chronic exposure to solar UV radiation suppresses immune reactions, and since such suppression has been implicated in the development of skin cancer."

Under the guidance of UW–Madison cancer researcher Hasan Mukhtar, the group has launched a program to define the cancer-curbing potential of phytochemicals and establish their mechanisms of action. "These phytochemicals essentially function in two ways," says Mukhtar. "The first way is to have the ability to scavenge highly damaging and reactive free radicals that are formed when the skin is exposed to solar UV rays. The second is through their effects on signal transduction molecules that are induced in the skin in response to UV rays."

Most of the evidence to date has come from laboratory data, mainly for reasons of cost and practicality. "Evidence from human trials continues to be quite limited, in large part because of the long period of photocarcinogenesis in humans," says Stephen Hsu, a molecular medicine professor at the Medical College of Georgia in Augusta. "These trials may take ten or more years in comparison to rodent studies, which can be completed in a matter of months." In addition, he says, the bioavailability of GTPs and GSPs in their original forms is very low, whether used orally or topically, so high doses had to be used in the animal studies to achieve the desired efficacy. The Wisconsin group notes in their review that combinations of antioxidant phytochemicals may therefore be necessary to achieve the desired level of photochemoprotection.

"Some skin care products already contain phytochemicals," says Afaq. "In conjunction with other sun-safe measures, use of these products may be an effective approach for reducing [UV-mediated] photodamage, inflammatory responses, photoaging, and skin cancer in humans." Afaq and Mukhtar assert that individuals can modify their dietary habits in combination with targeted use of skin care products and botanical antioxidants, perhaps eventually enabling people to enjoy the sun's health benefits [see "Benefits of Sunlight: A Bright Spot for Human Health," *EHP* 116:A160–167 (2008)] without the dermatologic consequences. —M. Nathaniel Mead

## The Beat

by Erin E. Dooley

### The Green Gap

A product may be greener than the competition, but that doesn't mean the product actually improves the environment. Consumers don't always grasp the distinction, however, as illustrated by the *2008 Green Gap Survey*, released in April 2008 by the Boston College Center for Corporate Citizenship and Cone LLC. The survey showed that while 39% of respondents prefer to use products

marketed as "green" or "environmentally friendly," nearly 48% misinterpret these terms as synonymous with "environmentally beneficial." This so-called green gap can lead consumers to believe products are "friendlier" than they actually are. Nearly half the respondents reported trusting companies to accurately portray the environmental impact of their products, a fact that Center for Corporate Citizenship director Bradley Googins says "may suggest the lack of control they feel around complex environmental issues." The FTC is currently reviewing guidance to help marketers avoid making inaccurate or misleading environmental claims.

### Metal Transformation

The U.K.'s Peak District, once a center of metal mining, is now an important recreation area, with an estimated 16 million people living within a 1-hour drive. Scientists reported at the April 2008 annual meeting of the Society for General Microbiology that the district is home not only to numerous rare animal and flower species but also to metal-eating bacteria, whose excretions may convert heavy metals in the soil into more soluble toxic forms that can leach easily into groundwater, reservoirs, and



Bog rosemary, a Peak District native

waterways. Furthermore, scientists believe changes in soil bacterial composition could help free carbon from the district's peat bogs, which store an estimated 24 metric tons of the material per square kilometer per year.

### Imaging FlowCytobot Nips Algal Blooms in the Bud

The Imaging FlowCytobot, an automated underwater cell analyzer developed at Woods Hole Oceanographic Institution (WHOI), is set to make beaches safer as the water warms up. The Imaging FlowCytobot quantifies and photographs microscopic plants in the water.



## TRANSPORTATION

## Hybrid Splash

Plug-in hybrid electric vehicles (PHEVs) are viewed as a major step in conserving oil and reducing emissions of greenhouse gases and other pollutants. So great is the hope for PHEVs that the U.S. Department of Energy announced in January 2008 it would invest up to \$30 million in the development and demonstration of these vehicles, which can run on both gasoline and electricity. A study scheduled for the 15 June 2008 issue of *Environmental Science & Technology* now cautions that the added electric load incurred by charging PHEV batteries would increase the amount of water used by power plants. This isn't necessarily a deal-breaker, the authors say, but planners need to prepare now to meet the demand.

The big difference between PHEVs and today's hybrids is the battery. Existing hybrids have a smaller battery that's charged by the gas engine. This is done, for example, by regenerative braking, which converts the energy from the speed of the car (kinetic energy) into electricity to be stored in the battery. A PHEV is similar, but its larger, as-yet undeveloped battery would be charged by plugging it into a household outlet, typically overnight.

The authors analyzed a range of figures on water consumption and withdrawal for both oil refining and electricity generation. Water that is "consumed" ends up in the atmosphere after use, whereas water that is "withdrawn" typically is returned to its source. They found that, compared with gas miles, up to 3 times the water per mile is consumed to power electric miles, and up to 17 times the water is withdrawn. This water is used primarily for cooling at power plants, where electricity is generated by steam-driven turbines. The steam clouds often seen rising from cooling towers indicate waste heat being dissipated into the atmosphere through evaporation.

Study coauthor Michael Webber, a University of Texas engineer who strongly favors the development and use of PHEVs, says local water policy planners need to be aware of this impact. "If they are in a place that has

a water-intensive power plant, and they think that plug-in hybrids will be important, they need to be preparing for that future demand because the increased load on the plant can increase the strain on local water resources," he says. To alleviate this impact, he says, power plants could consider using reclaimed water (e.g., treated wastewater) for cooling.

But Mark Duvall, project manager for electric transportation at EPRI, a nonprofit research organization funded by electric utilities, argues that PHEVs will not measurably increase electric utilities' water needs. He says utilities are certain to improve the efficiency in the way they use water over the next several decades. "Even if plug-in hybrids become the next big technology and become wildly successful, [the added electricity demand] will still be very small relative to all the electric loads we have today," he says.

Duvall projects that if PHEVs capture approximately 60% of the auto market by 2050, that will mean an increase in electric capacity of about 4% and a savings of 3–4 million barrels of oil per day. He says the electric sector has been growing by 1–2% annually, but the water withdrawal rate has remained constant.

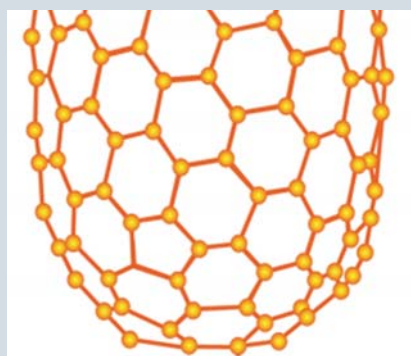
A crucial question in these calculations is how many PHEVs might eventually take to the roads. Duvall cautions that any estimates are purely speculative at this point and based largely on focus groups and similar tools. According to a survey cited in the 2001 EPRI report *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options*, more than half of respondents would pay 26.5% more for a hybrid than a conventional car if the hybrid could go 60 miles per charge cycle powered solely by electricity. Just over 7% would pay nearly 80% more for such a car.

But Duvall notes that actual customer behavior may be altered by a variety of conditions that were not present when the survey was done, such as gas prices. He says about 1 million regular hybrids are on the road right now, and he expects there may be a similar number between 2010 and 2018. Meanwhile, Saturn and Toyota in early 2008 announced they plan to market PHEVs within the next two years. —Harvey Black

The images are electronically relayed to shore-based laboratories, where software classifies the plankton. Researchers recently used the device to detect an unusual species of harmful algae in the Gulf of Mexico in time to prevent a shellfish poisoning outbreak in humans. This development comes just in time—marine surveys and new computer models also developed at WHOI forecast unusually large blooms of the toxic algae *Alexandrium fundyense* for New England in 2008.

### The Wonder Pollutant?

Single-walled carbon nanotubes (SWCNTs) are 10,000 times thinner than a human hair, stronger than steel, and more durable than diamonds—properties that have earned them the title of "wonder materials." But health and environmental advocates want more research on these materials before they spread any further in commerce. In the 7 May 2008 issue of *Nanotechnology*, scientists report that, unlike previously assumed, various commercially produced SWCNTs display vastly different compositions, which will make tracing their impact on human health and the environment more difficult. The authors conclude that failure to establish



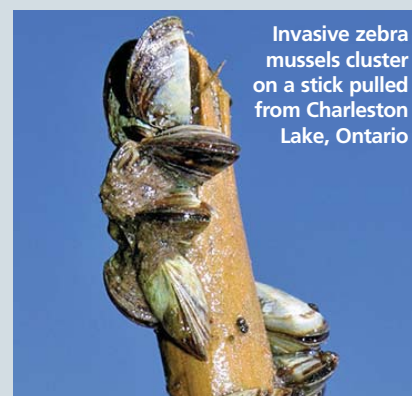
A mesh of carbon nanotubes

an understanding of the chemistry of these materials could result in unintended environmental consequences, eventually leading to product bans and expensive cleanup efforts like those associated with industrial materials such as asbestos.

### House Tackles Invasive Species

Hundreds of nonindigenous aquatic species are unintentionally introduced into U.S. waters through discharged ballast waters from oceangoing vessels, with a new invasive species being identified about every 28 weeks. These hitchhikers cause economic and ecologic

degradation to affected near-shore regions. On 24 April 2008, the U.S. House of Representatives passed HR 2830. Under the bill, oceangoing vessels have until 2013 to install ballast treatment equipment that can exceed by 100 times new international standards for the removal of invasive species. The bill also would establish a program to evaluate alternative ballast water treatment methods and an initiative to study methods for monitoring and controlling aquatic species spread by routes other than ballast water. At press time a companion Senate bill (S 1578) had not been voted on.



Invasive zebra mussels cluster on a stick pulled from Charleston Lake, Ontario